Do the New Metropolitan Life Insurance Weight-Height Tables Correctly Assess Body Frame and Body Fat Relationships?

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Abstract: The 1983 Metropolitan weight-height tables include elbow breadth as a measure of frame size. Such tables assume that frame measures provide an estimate of fat free mass and have little or no associations with body fat. These assumptions were evaluated in 437 Canadian adults for six frame measures by their associations with total body measures of fat and fat free mass. All six frame measures were similarly correlated with fat free mass, even when associations with height were taken into account. Wrist and ankle breadths were not associated with total body fat, while shoulder, elbow, hip, and knee breadths were so associated. Thus wrist and ankle breadths satisfy the assumptions inherent in the frame-weight-height tables better than elbow breadth and the other frame measures investigated. (*Am J Public Health* 1985; 75:1076–1079.)

Introduction

Public health workers and clinicians frequently use reference tables of appropriate weight for height for nutrition-related studies, programs, education, and diagnostic purposes. Among the most widely used weight-height tables have been those provided by the Metropolitan Life Insurance Company in 1959,[1] based on minimum subsequent mortality of insured adults in the United States and Canada. These tables provided "ideal" weight for ranges of height, according to sex and three categories of body frame, i.e., small, medium, large; there were no instructions on how frame size should be determined.

Recently, Metropolitan Life has published new tables based on pooled data from approximately 4.2 million insurance policies in the United States and Canada.[2] In these 1983 Metropolitan Life tables, frame is determined according to elbow breadth (bicondylar breadth of the humerus), and the elbow reference values were obtained from the 25th and 75th percentiles within height categories for United States adults participating in the First Health and Nutrition Examination Survey (HANES 1).[3] The elbow-frame categories were not based on minimum subsequent mortality as were weights for height.

The concern for considering frame size in assessing weight for height is not new.[4,5] A variety of body breadths have been suggested as measures of frame size.[6–8] Although the notion of body frame has not been defined precisely, a basic rationale for including body frame is that, in considering overweight, the health consequences of a given high level of weight for height are more severe for individuals with relatively smaller skeletal frame and muscularity (fat free mass) compared to individuals whose fat free mass is relatively large. The implications here are that the real target of evaluation is body fat rather than body weight per se[9] and that a measure of frame allows discrimination between those who are heavy because of large fat free mass from those whose overweight is largely fat.

In practice, the acceptance of the 1983 Metropolitan weight-height tables that include elbow breadth (or of other tables using different frame size measures) entails accepting tacit statistical assumptions regarding associations of fat and lean components of the body with measures used to represent frame: namely that the measures of frame size provide an estimate of fat free mass, and that the measures of frame size have little or no associations with body fat. To our knowledge, these assumptions have not been validated with reliable measures of total body composition. The present report investigates these two assumptions concerning such weight-height-frame tables, based on a sample of healthy Canadian adults for whom measures of body size and composition and six measures of frame size were available.

Methods

The sample includes 225 men and 212 women of French descent, 18–59 years of age who were residing within about 50 miles of Quebec City, Canada. All measurements were taken at the Laval University Physical Activity Sciences Laboratory. Height, weight, and six body breadths were measured according to protocols recommended by the International Biological Program.[10] Body breadths to be considered as frame size variables included: shoulder (biacromial breadth), elbow (bicondylar, humerus), wrist (bistyloid breadth), hip (biiliocristal breadth), knee (bicondylar, femur), and ankle (bimalleolar breadth). Body density was determined by hydrostatic weighing[11] and per cent body fat was calculated using the equation of Siri[12] and the mean of six valid measurements[13]; total fat weight and fat free mass were derived from the per cent body fat and body weight. Residual volume was measured in 140 of the subjects using the closed circuit helium dilution method.[14] For the remaining subjects, residual volume was estimated following the procedures of Kaltreider, *et al*,[15] which is based on measured vital capacity and an age adjustment. Comparison of the measured and estimated residual volumes for the 140 subjects showed that they were highly correlated ($r = 0.85$), and that they yielded very similar mean per cent body fat values (20.7 per cent ± 8.7 per cent, measured; 21.7 per cent ± 8.5 per cent, estimated).

Reliability of direct anthropometirc measurements was established from reexamination of 61 subjects, measured twice within two weeks. Intraclass reliability coefficients[16] were 0.92 for elbow breadth; 0.93 for wrist breadth; 0.94 for ankle, knee and shoulder breadths; and 0.99 for hip breadth, height and weight. Based on 26 sets of replicate measurements, per cent body fat and fat free mass were characterized by intraclass reliability coefficients of 0.98 and 0.99, respectively.

As a group, the study sample tends to be leaner than the US and Canadian populations, as indicated by weight-height

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relationships and skinfold thicknesses reported for national surveys.[17,18]

For the present study, the effects of age have not been considered in order to facilitate interpretation. While it may be argued that body composition changes with age are important and should not be ignored, the 1959 and 1983 Metropolitan tables do not consider age and a detailed consideration of age changes is beyond the scope of this report. Nevertheless, when age associations were included in the analyses, no major conclusions were altered.

Results

Using weight-height tables based on frame size assumes that the measure of frame size provides an estimate of fat free mass. Further, because frame categories are used within categories of height, it is assumed that the frame estimations of fat free mass extend beyond that provided by height alone. These relationships can be evaluated statistically as the correlations of measures of frame size with fat free mass, and as the partial correlations of frame size with free mass, controlling for associations with height (Table 1). In this case height approximates linearity as a covariate, which is assumed in partial correlation.

Fat free mass has substantial correlations with each of the frame size measures for men and women (Table 1). When these associations are diminished by controlling the effects of height, the partial correlations are moderate. There is little variation among frame measures in their partial correlations with fat free mass, although partial coefficients with knee breadth are marginally higher than those with other frame measures. The strength of the partial associations with fat free mass are sufficient to provide differences in mean fat free mass among groups classified by terciles of each frame size measure and adjusted for associations with height by analyses of covariance (not shown in Tables). Each of these frame size measures, then, meets the minimum requirements to satisfy the initial assumption.

As a corollary to the above assumption, use of weight-height tables based on elbow breadth or other measure of frame size assumes the measures of frame have little or no association with body fat. Because increases in fat free mass are also associated with increases in body fat,[19] one has to assume also that measures of frame have little or no association with body fat beyond that which can be accounted for by associations with fat free mass. Body fat in this case may be considered either as per cent of the body weight that is fat or as the absolute weight of fat in the body.

TABLE 1—Correlation of Frame Size Variables with Fat Free Mass ($r_{frame,FFM}$) and Partial Correlations Controlling for Height ($r_{frame,FFM.HT}$)*

Frame Variables	Men (n = 225) r	Men (n = 225) Partial r	Women (n = 212) r	Women (n = 212) Partial r
Shoulder	0.54	0.43	0.47	0.35
Elbow	0.45	0.30	0.46	0.38
Wrist	0.47	0.32	0.44	0.30
Hip	0.45	0.36	0.41	0.33
Knee	0.62	0.49	0.52	0.44
Ankle	0.49	0.30	0.48	0.31

*All coefficients are significantly different from zero ($p < 0.001$).

In statistical terms, the above relationships are equivalent to evaluating the correlations of measures of frame size with body fat, and the partial correlations of frame and body fat, controlling for associations with fat free mass (Table 2). Fat free mass is an approximately linear covariate in these analyses.

There is considerable variation in frame-size associations with body fat. Breadths of shoulder, elbow, hip, and knee all have partial correlations with per cent fat and fat weight when controlling fat free mass, while wrist and ankle breadths do not, given the present sample sizes. Relationships of frame variables with per cent body fat and fat weight are similar within sexes when controlling for fat free mass, but hip, knee, and elbow breadths have higher partial correlations with body fat in women compared to corresponding associations in men. The differences between partial correlation coefficients with elbow breadth and corresponding coefficients with other measures of frame size (Δr) and their 95 per cent confidence intervals demonstrate the magnitudes of deviation from the associations of fatness and elbow breadth. With these sample sizes, it is clear the ranges of probable differences from the elbow associations are considerable. Nevertheless, from these analyses, wrist and ankle breadths emerge as the frame measures that best satisfy the second assumption of little or no associations with body fat.

To the extent that frame measures are associated with body fat beyond that expected because they are correlated with fat free mass, one would expect ascending categorizations of weight by frame size to also increase in fatness. An example of the influence of such fat associations can be seen in Table 3, which presents means of per cent body fat for groups based on terciles of frame size, and adjusted for associations with fat free mass by analysis of covariance. Similar conclusions were drawn when fat weight or body weight were analyzed in the same manner. The most desirable measures of frame size should not have significant differences among adjusted means for per cent body fat when individuals are grouped by frame tercile categories. From Table 3 it is apparent that only wrist and ankle breadths meet this criterion, reflecting the partial correlations shown previously (Table 2). Differences between the first and third tercile groupings' adjusted means for elbow breadth are from 5–6 per cent body fat, and those for hip breadth reach about 10 per cent body fat (Table 3). The standard deviation of per cent body fat of the whole sample is about 7.5 per cent in each sex. Thus, tercile groupings of a measure like hip breadth can separate group means of body fat by greater than a standard deviation, after accounting for associations with fat free mass.

Discussion

If the 1983 Metropolitan weight-height tables[2] are used as widely as their 1959 predecessors or if recent recommendations to include frame in routine assessment[6,7,21] are implemented, the assumptions used in these methods concerning body composition should be understood. In the present report, the data were analyzed with respect to two particular assumptions derived from the new 1983 Metropolitan tables because of their probable widespread use. Nevertheless, some of the findings have much broader implications regarding the use of frame measures in assessing appropriate or average body weight.

The analyses confirm previous findings that boney breadths are correlated with fat free mass.[4,22] It is therefore

TABLE 2—Correlations of Frame Size Variables with Body Fat Measures ($r_{frame,fat}$) and Partial Correlations Controlling for Fat Free Mass ($r_{frame,fat.FFM}$)

	Per Cent Fat				Fat Weight			
Frame Variables	r	Partial r	Δr*	95% Confidence**	r	Parital r	Δr*	95% Confidence**
Men (n = 225)								
Shoulder	0.22	0.26	0.01	(−0.18, 0.19)	0.35	0.26	0.02	(−0.17, 0.20)
Elbow	0.22	0.25	—	—	0.33	0.24	—	—
Wrist	−0.01	−0.01	−0.26	(−0.42, −0.08)	0.11	−0.02	−0.26	(−0.42, −0.08)
Hip	0.41	0.47	0.22	(0.04, 0.39)	0.53	0.48	0.24	(0.06, 0.41)
Knee	0.23	0.30	0.05	(−0.14, 0.23)	0.39	0.30	0.06	(−0.13, 0.24)
Ankle	0.07	0.09	−0.16	(−0.33, −0.03)	0.19	0.08	−0.16	(−0.33, −0.03)
Women (n = 212)								
Shoulder	0.14	0.26	−0.12	(−0.30, −0.07)	0.30	0.26	−0.15	(−0.33, 0.04)
Elbow	0.25	0.38	—	—	0.46	0.41	—	—
Wrist	−0.08	0.00	−0.38	(−0.52, −0.18)	0.07	0.00	−0.41	(−0.56, −0.24)
Hip	0.48	0.62	0.24	(0.05, 0.41)	0.63	0.62	0.21	(0.02, 0.38)
Knee	0.33	0.50	0.12	(−0.07, 0.30)	0.53	0.52	0.11	(−0.08, 0.29)
Ankle	−0.02	0.08	−0.30	(−0.46, −0.11)	0.14	0.07	−0.34	(−0.50, −0.16)

*Difference from corresponding partial coefficient with elbow breadth.
**95% confidence intervals for Δ r calculated using z transformation (ref 20).

not surprising that such measures of frame have been used to render weight tables more specific to fatness than can be achieved when evaluating body weight alone, or in combination with height.

It has been shown here that frame size makes a contribution to fat free mass unique from its height contribution. Conceptually, this relationship may represent a skeletal robustness associated with relative muscularity. Accordingly, based on this property alone, it may seem appropriate to include frame size in weight tables even if height categories are incorporated into the evaluative scheme.

As a complicating factor, however, it has been shown that frame measures may have appreciable associations with total body fat. It has been well documented that body fat and fat free mass are not independent.[19] Especially in obese individuals, the larger fat mass is accompanied by relative increases in lean tissue also. In the present sample, correlations between fat free mass and fat weight were 0.17 and 0.26 in men and women, respectively. After accounting for associations with fat free mass, breadths of shoulder, elbow, hip, and knee still have significant partial correlations with per cent fat and total fat weight, while breadths of wrist and ankle have little association with fatness.

It has been suggested that correlations between body breadths and body fat are due to the inclusion of compressed subcutaneous fat thicknesses in the breadth measures.[23] Subcutaneous fat thicknesses are, of course, correlated with and part of total body fatness.[24] While this explanation seems plausible for measures like shoulder and hip breadths where there may be considerable subcutaneous fat, it seems less likely for knee breadth and especially elbow breadth where there is little subcutaneous fat over the points measured. In any case, clarification of this point remains to be proven with radiographic studies that can separate the boney breadth from its overlaying soft tissue. An alternative explanation is that body breadths are correlated with body fat because the boney dimensions have grown in response to excess weight. This may have occurred early in life or to a lesser extent after epiphyses have fused.

TABLE 3—Differences among Means of Per Cent Body Fat According to Tercile Groupings of Frame Size, Adjusted for Associations with Fat Free Mass by Analysis of Covariance

	Men (n = 225)				Women (n = 212)			
	Frame Terciles				Frame Terciles			
Frame Variables	1	2	3	p*	1	2	3	p*
Shoulder	19.0	21.2	26.5	0.000	28.7	30.8	32.8	0.009
Elbow	20.3	21.5	25.4	0.001	28.0	29.9	34.3	0.000
Wrist	22.5	21.3	22.6	0.498	30.3	30.4	31.5	0.556
Hip	17.9	21.2	27.5	0.000	26.2	29.4	36.8	0.000
Knee	19.7	22.5	24.6	0.002	26.8	29.6	35.6	0.000
Ankle	21.1	21.5	23.2	0.364	30.4	30.7	31.3	0.805

*Probability of chance occurrence determined by F statistic.

Because there is relatively little variation among frame size variables in their associations with fat free mass (Table 1), the extent of associations with body fat becomes an important factor in choosing an appropriate frame measure to be used with weight-height tables. In this regard wrist and ankle breadth meet the criteria better than the others investigated.

Elbow breadth already has been incorporated into the new 1983 Metropolitan tables. Because of associations with fat, frame size will tend to be underestimated in lean individuals and overestimated in relatively fat individuals compared to that expected if elbow breadth were unrelated to fatness. In the present sample this relationship amounts to 0.11 mm (± 0.028) of elbow breadth per kg of body fat in men and 0.21 mm/kg (± 0.032) in women. These estimates were calculated as partial regression coefficients of elbow breadth on fat weight, controlling for fat free mass. Almost identical estimates were obtained per kg of body weight, when controlling for fat free mass and/or height.

There are advantages and disadvantages in suggesting wrist and ankle breadths as frame size measures. Wrist breadth and ankle breadth can be measured at least as reliably as elbow breadth and the other frame measures considered.[25] Because of their anatomical locations, it is convenient to measure wrist or ankle breadth and no disrobing is necessary. On the other hand, there are no good national reference data available for wrist and ankle breadths of adults comparable to those available through HANES I for elbow breadth.[3]

There are several limitations to the sample and findings of this study. The sample is too small to allow the type of categorical analyses of weight, height, and frame size that one would like to validate weight-height-frame tables for populations. It is unlikely that the total population variation in fatness is represented fairly in the present sample. Nevertheless, the sample is relatively large when compared to other studies using total body measures of lean and fat components. The important issue is that the relationships among measures of frame size and body composition reported here are similar to those in the general population. Of course, this is difficult to determine, but general associations among variables in the present study are similar to those found in other studies.[4,19,22] Another limitation to the present findings is that they are based on external joint breadths, all of which include two compressed thicknesses of the overlaying skin and subcutaneous fat at the sites of measurement. Ideally, one would like to use boney breadths measured from radiographs exclusive of subcutaneous tissues. Nevertheless, in practical terms the important issues relate to bias introduced when the breadth measurements are collected as they would be in common practice, i.e., as external breadths, including subcutaneous tissue.

The present data do provide insights that are not available from analyses using only weight-height relationships or subcutaneous fat thicknesses as proxies for fat free mass and total body fatness.

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